Fast Pyrolysis of Lignocellulosic Biomass in the Gas-Solid Vortex Reactor

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The Gas-Solid Vortex Reactor (GSVR) enables fluidization in a centrifugal field with forces that exceed the gravitational force multiple times. A dense and uniform bed of particles with bed width-to-height ratios and gas-solid slip velocities much higher than in conventional fluidized beds can be sustained [1]. Due to the increased bed density, bed uniformity and bed width-to height ratios significant process intensification can be achieved. Larger gas-solid slip velocities lead to intensification of interfacial transfer of mass, energy and momentum and to drastic reduction of the gas-to-solid space time ratio. The presented work focuses on the design, construction and demonstration of a GSVR for the fast pyrolysis of biomass. Fast pyrolysis is regarded as one of key potential technologies for the production of chemicals, fuels and energy from biomass and the GSVR can provide advantages to this process.

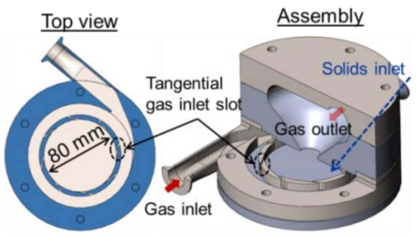

Figure 1. Gas-Solid Vortex Reactor schematics

The GSVR design consists of two concentric cylinders in which the fluidization gas is distributed around the annulus and enters the reactor chamber via eight rectangular 1 mm width inlet slots positioned at a 10° angle with respect to the tangent. The axial length of the reactor is 15 mm and the internal diameter of the reactor chamber is 80 mm. Biomass is fed into the reactor, next to the gas inlet slots, through a circular conduit of 10 mm diameter positioned at a 18° angle with respect to the horizontal plane as can be seen in Figure 1. Momentum is transferred from the gas to the particles, causing them to rotate and generating a large radially-outwards centrifugal force, which opposes the radially in-ward gas-solid drag force. Computational Fluid Dynamic simulations have shown that unreacted biomass tend to occupy the space next to the inner cylindrical wall [2]. Due to its lower size and density, char would be more expanded in the radial direction. Mass and energy balances on the GSVR showed that biomass mass flow rates from 1.4×10^{-4}-8.3×10^{-4} kg s^{-1} can be processed. The corresponding gas (N_2) mass flow rates and gas inlet temperatures are respectively 5.0×10^{-3}-1.0×10^{-2} kg s^{-1} and 800-923 K.

The operation conditions that maximize the yield of fast pyrolysis bio-oil have been established: high interfacial heat transfer, rapid removal of the pyrolysis vapors, and precise temperature control. Convective heat transfer coefficients of 300-450 $Wm^{-2}K^{-1}$, *i.e.*, three to five times those of conventional fluidized beds, can be reached in the GSVR. The estimated space time of the pyrolysis vapors before reaching the quenching section ranges from 50 to 110 ms. These space times are substantially lower than in rotating cone and fluidized bed fast pyrolysis reactors, varying from 0.5 to 2 s. The enhanced heat transfer and bed uniformity allows gaining improved control of the pyrolysis temperature. The simulations show that the temperature of the gas drops sharply after entering the reactor to a value which can be adjusted by the gas-to-biomass mass flow ratio. Biomass particles heat up almost instantaneously, until a value close to the final temperature of the gas. As a consequence of this improved temperature control and uniformity it is possible to produce bio-oils with a higher selectivity towards targeted components such as bio-aromatics.

The current demonstration unit consists of five sections: biomass feeding, gas heating, GSVR, char separation and bio-oil condensation. The biomass feeding section comprises a gravimetric feeder connected to an "*in-house*" developed injector screw. The gas heating section consists of a N_2 dewar connected in series with an electric vaporizer and two electric heating modules. Downstream of the GSVR, char is separated by means of a high throughput cyclone and a high efficiency cyclone. After leaving the reactor the pyrolysis vapors are tangentially send into a double tube heat exchanger integrated with an electrostatic precipitator. The heat exchanger is folded in a double U form, which allows collecting a carbon-rich and a water-rich oil. The fast pyrolysis process benefits in terms of yields and bio-oil quality from the advantages provided by the GSVR. The experimental set-up and results obtained with this unit will be discussed, with especial emphasis on its process intensification capabilities.

References

[1] Kovacevic JZ, Pantzali MN, Heynderickx GJ, Marin GB. Chem Eng Sci. 2014;106:293-303.
[2] Ashcraft RW, Heynderickx GJ, Marin GB. Chem Eng J. **2012**;207:195-208.

Acknowledgements (10 pt)

The SBO project "Bioleum" (IWT-SBO 130039) supported by the Institute for Promotion of Innovation through Science and Technology in Flanders (IWT) is acknowledged. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement n° 290793. PAR acknowledges financial support from a doctoral fellowship from the Fund for Scientific Research Flanders (FWO).The computational resources and services used in this work were provided by the VSC (Flemish Supercomputer Center), funded by the Hercules Foundation and the Flemish Government – department EWI.